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AGE OF THE VELA PULSAR PSR 0833-45

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It is shown that previous astrophysical methods of dating the young pulsar in Vela, PSR 0833-45, have effectively given upper limits to the true age. A value of 5000–8000 yr is found here to be not inconsistent with all available observational data. The historical significance of such a young age is briefly discussed.

Key words: pulsars—ages

The age of the young pulsar in Vela, PSR 0833-45, has been estimated by various authors to lie in the range $(1\text{–}10) \times 10^4$ yr. This note argues that the dating methods used in the past have given an exaggerated age and that the true age is probably closer to 5000–8000 yr. The object may therefore be of historical significance.

The standard method of dating a pulsar is based on the observed slowing down of the pulse period, P. If the rate of slowing is represented by

$$\dot{P} = K\,P^{2-n} \tag{1}$$

where n is called the braking index and K is a constant, then the pulsar's age as measured from an earlier time when its period was much shorter than its present period is just

$$\tau = (n-1)^{-1}\,(P/\dot{P}) \quad . \tag{2}$$

The simple theory of braking by magnetic dipole radiation predicts $n = 3$ (Pacini 1968; Goldreich and Julian 1969; Gunn and Ostriker 1969). Observed values of P and $\dot{P}$ for PSR 0833-45, combined with those for the fastest known pulsar (PSR 0531 + 21 in the Crab nebula), yield $n = 3.2$ if equation (1) is used with the same value of K for both pulsars. By making the reasonable assumption that $n = 3$, the so-called characteristic age τ is obtained, which, for the Vela pulsar, turns out to be 11,400 yr (Reichley, Downs, and Morris 1970), in agreement with the original estimate of $\sim 10^4$ yr given by Radhakrishnan et al. (1969). But this age will have to be revised upward if the discontinuous decreases of period (of which four (Downs 1978) have occurred since the pulsar's discovery in 1968) are allowed for, or if the braking index is estimated from the Crab pulsar's measured second derivative of period (Groth 1975), which yields $n = 2.5$ on the basis of the relation

$$P\,\ddot{P}/\dot{P}^2 = 2 - n \quad . \tag{3}$$

On the other hand, if the initial period was close to the present period, or if K decreases in time, as it would for a decaying magnetic dipole, τ will have to be modified downward. The point is that the characteristic age is not the true age, but only an approximation to it.

More indirect ways of estimating the age have been based on the nebulosity with which the pulsar is apparently associated (Kristian 1970). Shklovsky (1970) compared the surface brightness of the surrounding Vela X radio nebula with that of the Cygnus Loop (whose age was already known) in the framework of his theory of the evolution of type II supernova remnants; he was thus able to infer an age of 30,000–50,000 yr for Vela X. Wallerstein and Silk (1971) pointed out a number of unjustified assumptions in Shklovsky's comparison, and redetermined the age by applying a Sedov solution for a moving shock front to a combination of new optical and X-ray observations of Vela X; their result was $\sim$ 30,000 yr, which they later revised to 18,000 yr (Jenkins, Silk, and Wallerstein 1976). Similarly, Gorenstein, Harnden, and Tucker (1974) obtained a value of 13,000 yr. The estimated uncertainty of these ages is about a factor of 2. From proper-motion measurements of the optical filaments, van den Bergh (1973) and van den Bergh, Marscher, and Terzian (1973) concluded that either the age of the remnant is $\geq$ 10,000 yr or the supernova shell has been decelerated by the interstellar medium (it is also possible that the observed nebular material consists of shocked clouds moving more slowly than the blast wave itself, as suggested by McKee and Cowie (1975)). Therefore the true age could be smaller than 10^4 yr by an unknown factor.

The pulsar itself is not located at the center of Vela X (Large, Vaughan, and Mills 1968; van den Bergh, Marscher, and Terzian 1973). If it has moved significantly away from the center, it must have done so at high velocity because its age according to any determination is short. Previously, the present author made a general suggestion that, to account for the high galactic latitudes and spatial pairs of some pulsars, these stars could be interpreted as high-velocity "runaways" from disrupted close binary systems (Stothers 1969). Among several developers of this idea (Gott, Gunn, and Ostriker 1970; Prentice 1970), Seward et al. (1971) used it specifically to estimate the age of PSR 0833-45 from its location in Vela X, and found, tentatively, a value of $\sim 10^5$ yr. On the other hand, since the nebula is asymmetrical in form, the eccentric location of the pulsar is more likely due to the asymmetrical expansion of the nebula (Large, Vaughan, and Mills 1968), as Seward et al. themselves were aware. Therefore, 10^5 yr should be regarded as only an upper limit.

Last, a more formal upper limit of 10^7 yr can be placed by the conventional method of dating the stellar association to which the pulsar apparently belongs (Brandt et al. 1971; Upton 1973; Straka 1973). This upper limit is not very useful, in view of the more stringent limits already discussed and in view of the discovery of optical pulses (Wallace et al. 1977), which suggest an age less than $\sim 10^5$ yr.

It is clear that only the characteristic age τ provides a plausible approximation, rather than a generous upper limit, to the true age. How can this age be checked? At present, there are two possible approaches. One approach makes use of data for the Crab pulsar, whose true age is known to be 925 yr (as dated from the supernova witnessed in A.D. 1054). This age falls short of the pulsar's characteristic age, which is 1250 yr. The ratio of the two ages is 1.35.

The second approach links the large observed galactic heights of old pulsars to their high observed velocities. Under the reasonable assumption that these pulsars originated close to the galactic plane (where most supernova remnants are observed), Taylor and Manchester (1977) computed kinematical ages, which should be very close, on the average, to the pulsars' true ages. By adopting the somewhat more accurate data of Helfand and Tademaru (1977), who conducted a similar study, the ratio of the average characteristic age to the average kinematical age turns out to be 1.6 ± 1.5, 5.7 ± 3.4, and ~ 20 for the following selected intervals of characteristic age: $(2.0\text{–}3.9) \times 10^6$ yr (3 pulsars), $(4.0\text{–}5.9) \times 10^6$ yr (3 pulsars), and $(2\text{–}2000) \times 10^6$ yr (all old pulsars). It therefore appears that the characteristic age τ *exceeds* the true age by a factor that monotonically increases with τ.

Since the Vela pulsar is located chronologically between the Crab pulsar and the average old pulsar, it is reasonable to conclude that its characteristic age may be larger than its true age by a factor of 1.35–2. This would imply that its true age could be approximately 5000–8000 yr, or that the event which produced the pulsar could have occurred at some time during the interval 3000 to 6000 B.C.

Such a recent possible date marks the event as being of some historical interest. Although there is no tradition of it in ancient Far Eastern (Clark and Stephenson 1977) or Greco-Roman (Stothers 1977) literature, Michanowsky (1979) has found some evidence for a stellar explosion in Vela-Puppis from a Sumero-Akkadian astronomical text of c. 1000 B.C., which includes information of much earlier date. Since the context of this information is partly religious and mythological, a date for the explosion preceding the invention of cuneiform writing (c. 3000 B.C.) appears likely, if Michanowsky's interpretation is correct; yet a date too far in the past would not account for the transmission of the star's precise position as afforded by the relatively late text. It would therefore seem that the "historical" date can be reconciled with the astronomical date if the revision of the latter date, as given above, is accepted.

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